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BASIC OSCILLOSCOPE APPLICATIONS

DC Voltage Measurements

Measurement of a Simple DC Voltage
(Refer to Fig. 21)

This technique is used to measure the level of a simple dc voltage where no waveform is present. This would result, for example, from connecting the scope directly to the output of a dc power supply. The example uses +5 volts dc, which is a common supply voltage used in digital circuits. Though this measurement can be performed on either scope channel, this example uses channel 1.

1. Set the scope to display channel 1, single-trace. Set triggering for auto. This will produce a trace even when only dc voltage is present.

2. Set the channel 1 input coupling switch to the ground position. Adjust the horizontal and vertical position controls to obtain a straight line trace, as in Fig. 21a. This horizontal line becomes the zero volt reference line for the measurement. This example uses a line near the bottom of the screen; your choice may depend on how much resolution is desired, or whether negative voltages may be encountered.

3. Once the vertical position is adjusted, do not disturb the vertical position control.

4. Connect the oscilloscope ground clip to a suitable ground point and connect the channel 1 probe to the point where the dc voltage is to be measured.

5. Set the channel 1 input coupling switch to DC. Adjust the channel 1 Volts/Div switch to display a straight line trace, as in Fig. 21b. If the voltage is a positive dc voltage, the line will display above the zero reference position, as in the figure. If the trace does not immediately appear. it may be deflected off the screen; readjust the Volts/Div control to a less sensitive setting until a trace is obtained. For best accuracy, try to use a setting that gives at least three divisions of deflection from the ground reference.

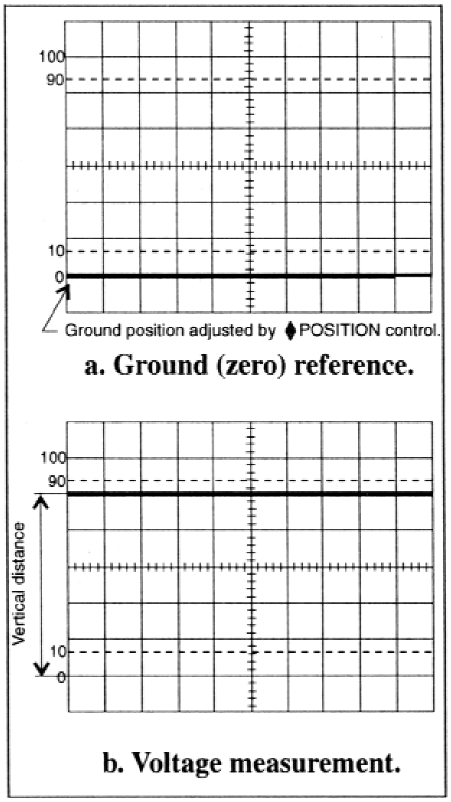
100
90
10
0
Ground position adjusted by ♦POSITION control.
a. Ground (zero) reference.
100
90
Vertical distance
10
0
b. Voltage measurement.

Fig. 21. DC voltage measurement.

Note:

Changing the Volts/Div setting may slightly alter the reference level. When you change Volts/Div, you should also momentarily switch the input coupling switch back to ground and readjust the reference level as required.

6. Make sure that the VARIABLE Volts/Div control is set to the CAL position. Measure the vertical distance from the zero reference level to the displayed trace.

7. Multiply the distance measured above by the Volts/Div setting and the probe attenuation ratio as well. Voltages above the reference level are positive and voltages below the reference level are negative.

The measurement is summarized by the following equation:

DC level = Vert Div x Volts/Div x Probe.

For the example shown in Fig. 21, the point being measured is 5.0 divisions from the reference level (ground potential). If the Volts/Div control is set to 0.1 V and a 10:1 probe is used, the dc voltage level is calculated as follows:

DC level = 5.0 (div) x 0.l (V/div) x 10=5.0 V.

Instantaneous DC Voltage Measurements

(Refer to Fig. 22)

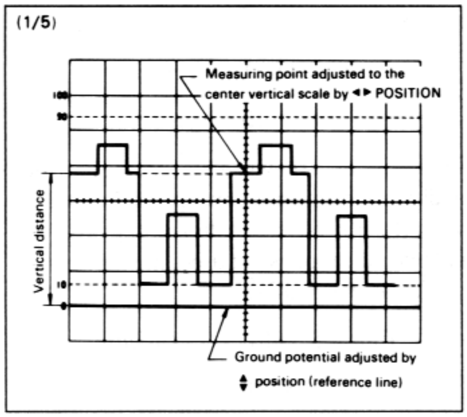
(1/5)
Measuring point adjusted to the center vertical scale by ◄► POSITION
100
90
Vertical distance
10
0
Ground potential adjusted by ♦ position (reference line)

Fig. 22. Instantaneous DC voltage measurement.

This technique may be used to measure an instantaneous dc level at some point on a waveform, such as that in Fig. 22. Though this measurement can be performed on either scope channel, this example uses channel 1.

1. Connect the signal to be measured to the channel 1 input jack, and set the oscilloscope to display channel 1, single-trace. Set the Volts/Div and Time/Div controls to obtain a normal display of the waveform to be measured. The variable input attenuator control must be set to the CAL position.

2. Select auto triggering and set the input coupling switch to the ground position. This establishes the zero-volt reference trace. Using the vertical position control, adjust the trace to the desired reference level position, making sure not to disturb this setting once it is made.

3. Set the channel 1 input coupling switch to the DC position to observe the waveform,

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including its dc component. If an inappropriate reference level position was selected in step 2, or an inappropriate Volts/Div setting was made, the waveform may not be visible at this point (deflected completely off the screen). This is especially true when the dc component is large with respect to the waveform amplitude. If so, reset the Volts/Div control and repeat steps 2 and 3 until the waveform and the zero reference are both on the screen.

4. Use the horizontal position control to bring the portion of the waveform to be measured to the center vertical graduation line of the graticule scale.

5. Measure the vertical distance from the zero reference level to the point to be measured (at least 3 divisions desirable for best accuracy). The reference level can be rechecked by momentarily returning the input coupling switch to the ground position.

6. Multiply the distance measured above by the Volts/Div setting and the probe attenuation ratio as well. Voltages above the reference level are positive and voltages below the reference level are negative.

The measurement is summarized by the following equation:

Instantaneous DC level =
Vert Div x Volts/Div x Probe.

For the example shown in Fig. 22, the point being measured is 3.8 divisions from the reference level (ground potential). If the Volts/Div control is set to 0.2 V and a 10:1 probe is used. the dc voltage level is calculated as follows:

Instantaneous DC level =
3.8 (div) x 0.2 (V/div) x 10 = 7.6 V.

Peak-To-Peak Voltage Measurements

(Refer to Fig. 23)

This procedure may be used to measure peak-to-peak voltages, or for measuring the voltage difference between any two points on a waveform.

1. Connect the signal to be measured to the input connector, set the oscilloscope to display the channel that you wish to use, and set the input coupling switch to the AC position. Set the Volts/Div and Time/Div controls to obtain a normal display of the waveform to be measured. The variable input attenuator control must be set to the calibrated position.

2. Using the vertical position control, adjust the waveform position such that one of the two points falls on a major horizontal graduation line.

3. Using the horizontal position control, adjust the second point to coincide with the center vertical graduation line.

4. Measure the vertical distance between the two points (at least 3 divisions desirable for best accuracy). Multiply the number of divisions by the setting of the Volts/Div control. If a probe is used, further multiply this by the probe attenuation ratio.

The measurement is summarized by the following equation:

Voltage =Vert Div x Volts/Div x Probe.

For the example shown in Fig. 23, the two points are separated by 4.4 divisions vertically. If the Volts/Div control setting is 20 mV and a 10:1 probe is used, the voltage is calculated as follows:

Voltage =
4.4 (div) x 20 (mV/div) x 10 = 880 mV.

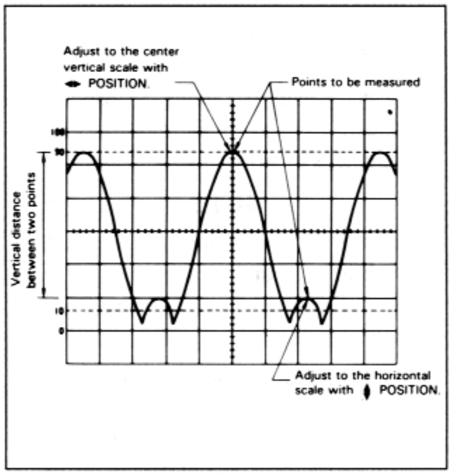
Adjust to the center vertical scale with ◂▸ POSITION.
Points to be measured
100
90
10
0
Vertical distance between two points
Adjust to the horizontal scale with ▴▾ POSITION.

Fig. 23. Voltage measurement.

Add Mode Applications

Differential Measurements
(Refer to Figs. 24 and 25)

The oscilloscope's "add" mode can be conveniently used to measure a signal with a reference point other than earth ground. For example, if you wanted to measure the signal present across R2 in Fig. 24, you would use the following technique:

1. Connect the channel that can be inverted to the desired reference point and connect the other channel to the desired point of measurement.

2. Select the subtract mode of operation by selecting the add mode and inverting the channel connected to the reference point.

3. Adjust the Volts/Div controls for both channels and adjust the Time/Div control to obtain a normal display of the waveform to be measured. The variable input attenuator controls must both be set to the calibrated position to make voltage measurements. Also, make sure that both Volts/Div controls are set the same.

4. Using the vertical position controls, adjust the waveform position such that one of two points fall on a major horizontal graduation line.

5. Using the horizontal position control, adjust the second point to coincide with the center vertical line.

6. Measure the vertical distance between the two points (at least 3 divisions desirable for best accuracy). Multiply the number of divisions by the setting of either Volts/Div control. If probes are used, further multiply this by the attenuation ratio of either probe (make sure that both probes are of the same attenuation ratio).

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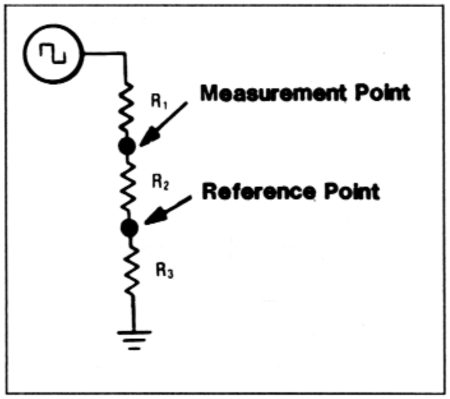

Fig. 24. Voltage measurement with reference other than earth ground.

The measurement is summarized by the following equation:

Voltage =
Vert Div x Volts/Div x Probe.

For the example shown in Fig. 25, the two points are separated by 4.5 divisions vertically. If the Volts/Div setting is 0.1 V and 10:1 probes are used, the voltage is calculated as follows:

Voltage =
4.5 (div) x 0.1 (V/div) x 10 = 4.5 V

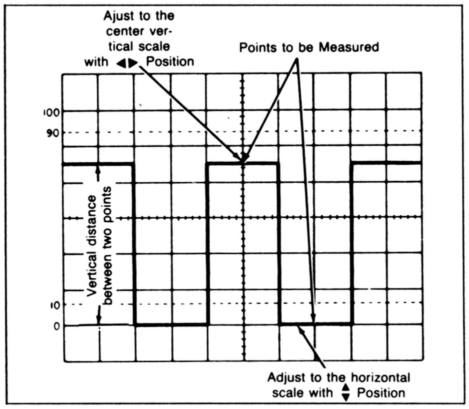
Ajust to the center vertical scale with ◀▶ Position
Points to be Measured
100
90
10
0
Vertical distance between two points
Adjust to the horizontal scale with ▲▼ Position

Fig. 25. Differential voltage measurement.

Elimination of an Undesired Signal Component

(Refer to Fig. 26)

Another application of the add mode is to cancel out the effect of an undesired signal component which is superimposed on the signal you wish to observe (for example, undesired 60 Hz hum superimposed on an rf signal). The first waveform of Fig. 26 shows such a composite waveform, although in this simplified illustration the two signals are relatively close to each other in frequency.

1. Apply the signal containing an undesired component to one channel (the channel that cannot be inverted) and the undesired signal itself alone to the other channel (the channel that can be inverted).

2. Select the dual-trace and chop display modes and set the trigger source switch to the channel that can be inverted. Adjust the controls to display two signals. Verify that one of the traces represents the unwanted signal in reverse polarity. If not, reverse the polarity of that channel using the invert function.

3. Now set the oscilloscope for single-trace display: Set the trigger source for the channel that is connected to the undesired signal by itself and set the scope for the add mode of operation. Adjust the Volts/Div and variable input attenuator controls for the channel that can be inverted so that the undesired signal component is canceled as much as possible. The remaining signal should be the signal you wish to observe alone, free of the unwanted signal. Such a result is shown in the bottom waveform of Fig. 26.

Push-Pull Amplifier Measurements

The oscilloscope's add mode can also be conveniently used to make signal measurements and check for proper balance at the outputs of push-pull amplifiers.

1. Connect one channel to one amplifier output and the other channel to the other amplifier output.

2. Select the subtract mode of operation by selecting the add mode and inverting one channel's polarity.

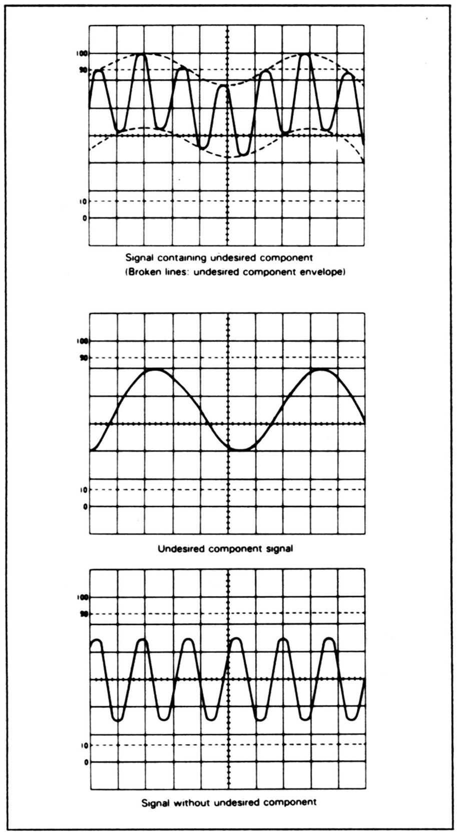
100
90
10
0
Signal containing undesired component
(Broken lines: undesired component envelope)
Undesired component signal
Signal without undesired component

Fig. 26. Eliminating an undesired signal component

Note:

Because the two outputs of a push-pull amplifier are out of phase, they tend to subtract. It is necessary to invert one channel to cause the signals to add.

3. Adjust the Volts/Div and time base controls to obtain a normal display of the waveform to be measured. The variable input attenuator controls must both be set to the calibrated position to make voltage measurements. Also, make sure that both step input attenuator controls are at the same settings.

4. Make peak-to-peak signal measurements by performing steps 4 through 6 of "Differential Voltage Measurements".

5. To check amplifier balance, return the inverted channel to normal polarity and observe the display. If the amplifier is perfectly balanced, the two outputs should fully cancel each other. The

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resulting displayed waveform should be a flat trace. Any displayed signal equals the imbalance.

Time Measurements

(Refer to Fig. 29)

This is the procedure for making time (period) measurements between two points on a waveform. The two points may be the beginning and ending of one complete cycle if desired.

1. Connect the signal to be measured to the input connector and set the oscilloscope to display the channel to be used. Set the Volts/Div and Time/Div controls to obtain a normal display of the waveform to be measured. Be sure the variable time base control is set to the calibrated position.
2. Using the vertical position control, set one of the points to be used as a reference to coincide with the horizontal center line. Use the horizontal position control to set this point at the intersection of any vertical graduation line.
3. Measure the horizontal distance between the two points (at least 4 divisions desirable for best accuracy). Multiply this by the setting of the step main time base control to obtain the time between the two points. If Xl0 magnification is used, multiply this further by 1/10.

The measurement is summarized by the following equation:

Time =
Hor Div x Time/Div
(x 1/10 if X10 Mag is used)

For the example shown in Fig. 27, the horizontal distance between the two points is 5.4 divisions. If the Time/Div control setting is 0.2 mS and magnification is not used, the time period is calculated as follows:

Time = 5.4 (div) x 0.2 (mS/div)
= 1.08 mS.

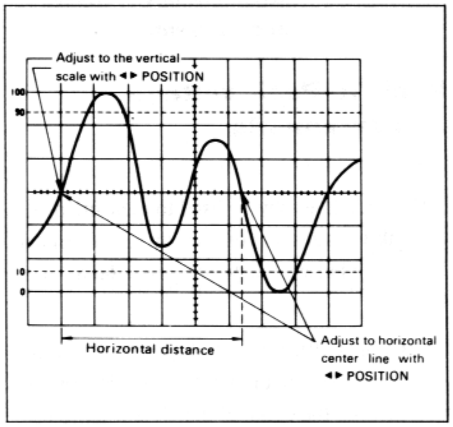

Adjust to the vertical scale with ◄► POSITION
100
90
10
0
Horizontal distance
Adjust to horizontal center line with ◄► POSITION

Fig. 27. Time measurement.

Frequency Measurements

Method No. 1

(Refer to Fig. 28)

Frequency measurements are made by measuring the time period of one cycle of a waveform and calculating the frequency, which equals the reciprocal of the time period.

1. Set up the oscilloscope to display one full cycle of the waveform (see Fig. 28).
2. Measure the time period of one cycle and calculate the frequency as follows:

Freq = 1/Period

In the example shown in Fig. 28, a period of 40 mS is observed. Substituting this value into the above equation, the frequency is calculated as follows:

$$\text{Freq} = \frac{1}{40 \times 10^{-6}}$$

$$= 2.5 \times 10^{4}$$

= 25 kHz

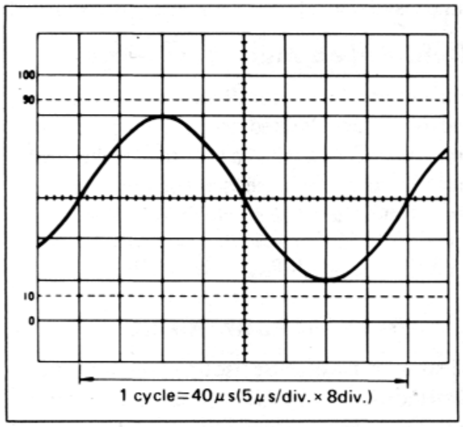


Fig. 28. Frequency measurement.

Method No. 2

(Refer to Fig. 29)

While the previously described method relies on direct period measurement of one cycle, the frequency can also be measured by counting the number of cycles present in a given time period.

1. Set up the oscilloscope to display several cycles of the waveform. The variable time base control must be set to the calibrated position.
2. Count the number of cycles of waveform between a chosen set of vertical graduation lines (see Fig. 29).
3. Multiply the number of horizontal divisions by the Time/Div control setting to calculate the time span. Multiply the reciprocal of this value by the number of cycles present in the time span. If X10 magnification is used, multiply this further by 10. Note that errors will occur for displays having only a few cycles.

The measurement is summarized by the following equation:

$$\text{Freq} = \frac{\text{No of Cycles (x 10 for X10 Mag)}}{\text{Hor Div x Time / Div}}$$

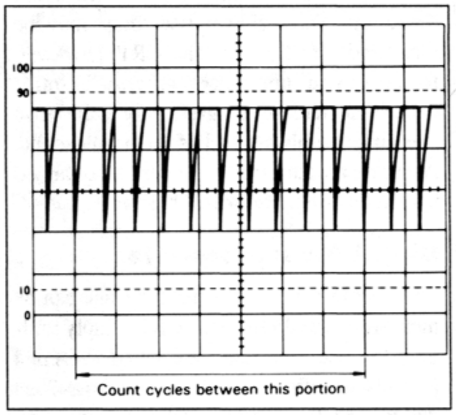


Fig. 29. Alternate method of frequency measurement.

For the example shown in Fig. 29, there are 10 cycles within 7 divisions. If the Time/Div control setting is 5 mS and magnification is not used, the frequency is calculated as follows:

$$\text{Freq} = \frac{10\ (\text{cycles})}{7\ (\text{div}) \times 5\mu\text{S}} = 205.7\ \text{kHz}$$

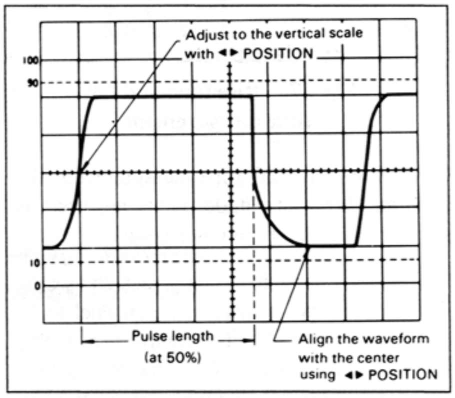

Adjust to the vertical scale with ◄► POSITION
100
90
10
0
Pulse length (at 50%)
Align the waveform with the center using ◄► POSITION

Fig. 30. Pulse width measurement.

Pulse Width Measurements

(Refer to Fig. 30)

1. Apply the pulse signal to one of the oscilloscope's input jacks and set the scope to display the channel to be used.
2. Use the Volts/Div and Time/Div controls to adjust the display so the waveform is easily observed. Use the vertical position control to position the pulse over the center horizontal graduation line. Use the horizontal position control to align the leading edge of the pulse with one of the vertical graduation lines.
3. Measure the distance between the leading edge and trailing edge of the pulse (along the center horizontal graduation line). Be sure that the variable time base control is set to the calibrated position. Multiply the number of horizontal divisions by the step main time base control setting and if Xl0 magnification is used, further multiply this value by 1/10.

The measurement is summarized by the following equation:

Pulse Width =
Hor Div x Time/Div
(x 1/10 if X10 Mag is used).

For the example shown in Fig. 30, the pulse width at the center of the pulse is 4.6 divisions. If the time/div control setting is 0.2 mS and X10 magnification is used, the pulse width is calculated as follows:

Pulse Width =
4.6 (div) x 0.2 (mS/div) x 1/10
= .092 mS or 92 mS.

Pulse Rise Time and Fall Time Measurements

Method No. 1
(Refer to Fig. 31)

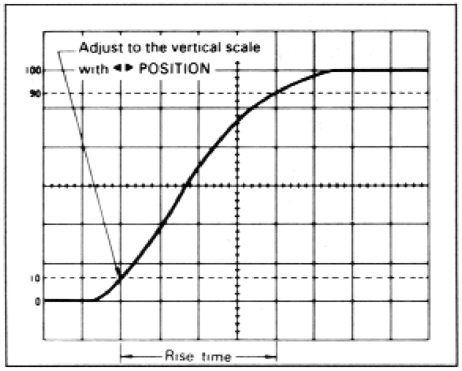


Fig. 31. Rise time and fall time measurement

For rise time and fall time measurements, the 10% and 90% amplitude points are used as starting and ending reference points.

1. Apply a signal to the input jack and set the oscilloscope to display the channel to be used. Use the Volts/Div control, the variable input attenuator control, and the vertical position control to adjust and position the waveform on the 0% and 100% markers. Ignore any overshoot or aberrations.

2. Set the Time/Div control to as fast a setting as possible while still being able to observe both the 10% and 90% points. Set the variable time base control to the calibrated position.

3. Use the horizontal position control to adjust the 10% point to coincide with a vertical graduation line and measure the horizontal distance in divisions between the 10% and 90% points on the waveform. Multiply this by the Time/Div control setting and also by 1/10 if the X10 magnification mode was used.

Note:

Be sure that the correct 10% and 90% lines are used. For such measurements, the 0, 10, 90, and 100% points are marked on the CRT screen.

The measurement is summarized by the following equation:

Rise Time = Hor Div x Time/Div
(x 1/10 if X10 Mag is used).

For the example shown in Fig. 31, the horizontal distance is 4.0 divisions. The Time/Div control setting is 2 mS. The rise time is calculated as follows:

Rise Time =
4.0 (div) x 2 (µS/div) = 8 µS

Method No. 2
(Refer to Fig. 32)
The following step can be substituted for step 3 in Method No. 1:

Use the horizontal position control to set the 10% point to coincide with the center vertical graduation line and measure the horizontal distance to the point of the intersection of the waveform with the center horizontal line. Let this distance be D1. Next, adjust the waveform position so that the 90% point coincides with the vertical centerline and measure the distance from that line to the intersection of the waveform with the horizontal centerline. Let this distance be D2. The total horizontal distance is D1 plus D2.

The following equation summarizes the measurement:

IMPORTANT CONSIDERATIONS FOR RISE TIME AND FALL TIME MEASUREMENTS

Error in Observed Measurements
The observed rise time (or fall time) as seen on the CRT is actually the cascaded rise time of the pulse being measured and the oscilloscope's own rise time. The two rise times are combined in square law addition as follows:

$$T_{observed} = \sqrt{(T_{pulse})^2 + (T_{scope})^2}$$

The effect of the oscilloscope's rise time is almost negligible when its rise time is at least three times as fast as that of the pulse being measured. Thus, slower rise times may be measured directly from the CRT. However, for faster rise time pulses, an error is introduced that increases progressively as the pulse rise time approaches that of the oscilloscope. Accurate measurements can still be obtained by calculation as described below.

Direct Measurements
To determine the fastest rise time that can be measured directly from the CRT, simply multiply the rise time rating of the oscilloscope by a factor of 3. This will tell you the minimum allowable duration of rise time measurable directly from the CRT. However, since the rise time of the signal you are observing is not known, it is easier to determine the minimum number of divisions that the rise time pulse should occupy so that it can be measured directly from the CRT. Most rise times are measured at the fastest sweep speed and using X10 magnification. If you are using a 100 MHz oscilloscope with a rise time of 3.5 ns and the maximum sweep speed is 2 ns/div with X10 Mag, you would not want to make direct rise time measurements of less than 10.5 ns, or 5.25 divisions.

Calculated Measurements
For observed rise times of less than three times the oscilloscope's rise time, the pulse rise time should be calculated to eliminate the error introduced by the cascaded oscilloscope rise time. Calculate pulse rise time as follows:

$$T_{observed} = \sqrt{(T_{pulse})^2 - (T_{scope})^2}$$

Limits of Measurement
Measurements of pulse rise times that are faster than the scope's rated rise time are not recommended because a very small reading error introduces significant error into the calculation. This limit is reached when the "observed" rise time is about 1.3 times greater than the scope's rated rise time.

Probe Considerations
For fast rise time measurements that approach the limits of measurement, direct connection via 50-ohm coaxial cable and 50-ohm termination is recommended where possible. When a probe is used, its rise time is also cascaded in square law addition. Thus, the probe rating should be considerably faster than the oscilloscope if it is to be disregarded in the measurement.

Rise Time = (D1 + D2) x Time/Div
(x 1/10 if X10 Mag is used).

For the example shown in Fig. 32, D1 is 3.8 divisions and D2 is 2.2 divisions. If the Time/Div control setting is 2 ms, the rise time is calculated as follows:

Rise Time = (1.8 + 2.2) x 2 (µS/div)=8 µS

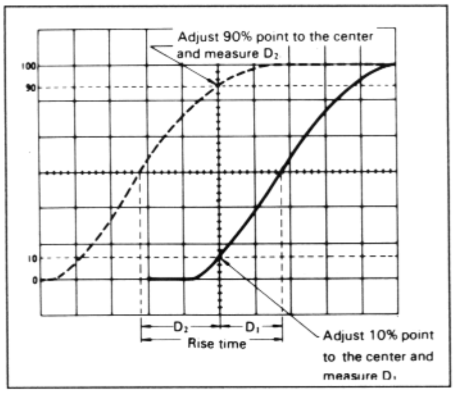

Adjust 90% point to the center and measure D2
100
90
10
0
D2
D1
Rise time
Adjust 10% point to the center and measure D1

Fig. 32. Alternative rise time and fall time measurement

Percentage of Modulation Measurements

(Refer to Fig. 33)

This procedure is useful in measuring the percentage of modulation in an AM (amplitude modulation) signal.

1. Connect the modulated signal to the channel 1 input jack.

2. Adjust the oscilloscope controls for a stable display of several cycles of the modulated signal.

3. Adjust the Volts/Div and variable input attenuator controls so that several divisions of vertical amplitude are displayed. Since this measurement simply calls for a ratio, it is not necessary to be concerned with the scale factor (Volts/Div).

The percentage of modulation is determined by dividing two times the modulation depth by the unmodulated carrier level and multiplying the result by 100. The following equation summarizes the measurement:

$$\text{Percent of Modulation} = \frac{2B}{A} \times 100$$

where:
A = Unmodulated carrier level (in divisions)
B = Modulation depth (in divisions)

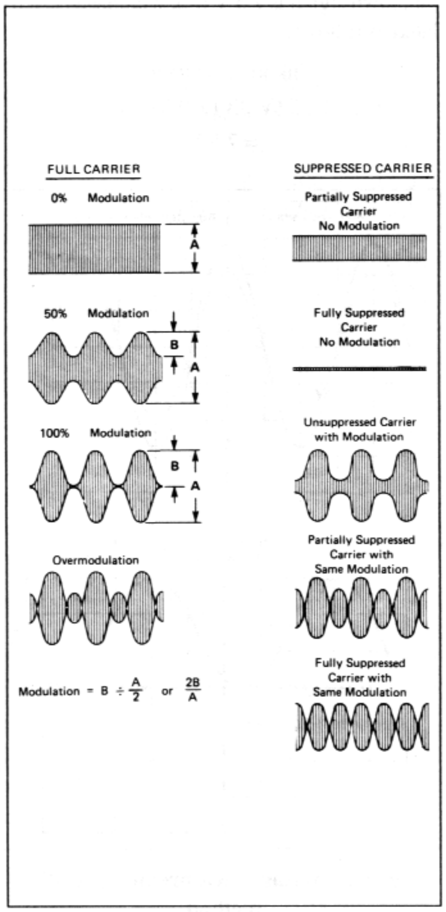

FULL CARRIER
0% Modulation
A
50% Modulation
B
A
100% Modulation
B
A
Overmodulation
Modulation = B ÷ A/2 or 2B/A
SUPPRESSED CARRIER
Partially Suppressed Carrier No Modulation
Fully Suppressed Carrier No Modulation
Unsuppressed Carrier with Modulation
Partially Suppressed Carrier with Same Modulation
Fully Suppressed Carrier with Same Modulation

Fig. 33. Percent of modulation measurement

For the first example shown in Fig. 33, there is no modulation depth so the percentage of modulation is obviously zero. The waveform in the second example in Fig. 33 has a modulation depth of 1 division and an unmodulated carrier level of 4 divisions. The percentage of modulation is 50%, which was calculated as follows:

$$\frac{2 \times 1}{4} \times 100 = 50\%$$

The waveform in the third example of Fig. 33 has a signal with a modulation depth of 2 divisions and an unmodulated carrier level of 4 divisions. The percentage of modulation is 100%, which was calculated as follows:

$$\frac{2 \times 2}{4} \times 100 = 100\%$$

The fourth and final example in Fig. 33 represents an overmodulated signal. Once modulation exceeds 100%, there is no need to calculate the percentage.

Time Difference Measurements

(Refer to Fig. 34)

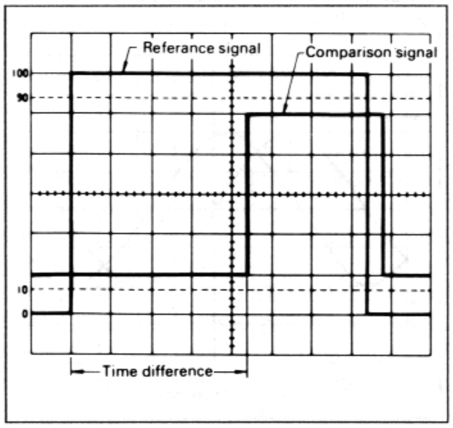


Fig. 34. Time difference measurement.

This procedure is useful in measurement of time difference between signals that are synchronized to one another but skewed in time.

1. Apply the two signals to the oscilloscope's input jacks and select the dual-trace display mode (either the chop or alternate display mode). Chop is usually chosen for low-frequency signals and alternate for high-frequency signals.

2. Set the scope to trigger on the channel that gives the most stable display. Use the Volts/Div and Time/Div controls to obtain an easily observed display of both signals.

3. Use the vertical position controls to superimpose both waveforms to intersect the center horizontal graduation line as shown in Fig. 34. Use the horizontal position control to set the reference signal coincident with one of the vertical graduation lines.

4. Measure the horizontal distance between the two signals and multiply this distance (in divisions) by the step main time base setting. If

X10 magnification is used, multiply this again by 1/10.

The measurement is summarized by the following equation:

Time = Hor Div x Time/Div
(x 1/10 if X10 Mag is used)

For the example shown in Fig. 34, the horizontal distance measured is 4.4 divisions. If the Time/Div control setting is 0.2 mS and X10 magnification is not used, the time difference is calculated as follows:

Time = 4.4 (div) x 0.2 (mS/div)
= 0.88 µS or 880 µS

Phase Difference Measurements

Method No. 1
(Refer to Fig. 35)

This procedure is useful in measuring the phase difference of signals of the same frequency.

1. Apply the two signals to the oscilloscope's input jacks and select the dual-trace display mode (either alternate or chop display mode).

2. Select the signal which is leading in phase as the trigger source and use the Volts/Div and variable input attenuator controls to adjust the two waveforms so they are equal in amplitude.

3. Use the vertical position controls to position the waveforms in the vertical center of the display. Use the Time/Div and variable time base controls to adjust the display so that one cycle of the reference signal occupies 8 divisions horizontally (see Fig. 35). The trigger level and horizontal position controls are also useful in achieving this display. The display should be as shown in Fig. 35, where one division now represents 45° in phase.

4. Measure the horizontal distance between corresponding points on the two waveforms. Multiply the distance (in divisions) times 45° per division to obtain the phase difference.

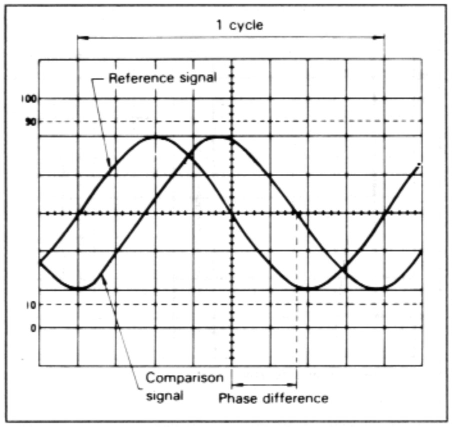


Fig. 35. Phase difference measurement.

The measurement is summarized by the following equation:

Phase Difference = Hor Div x 45°/Div

For the example shown in Fig. 35, the horizontal distance is 1.7 divisions. Thus, the phase difference is calculated as follows:

Phase Difference = 1.7 x 45°/div = 76.5°

Method No. 2
(Refer to Fig. 36)

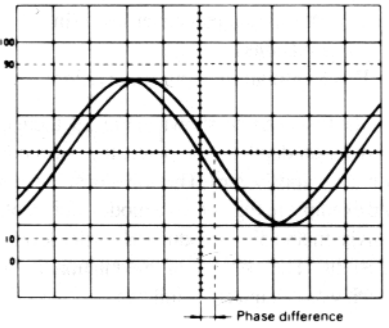
The above procedure allows 45° per division, which may not give the desired resolution for small phase differences.

If greater accuracy is required, the Time/Div control setting may be changed to expand the display as shown in Fig. 35, but the variable time base control setting must not be touched. If necessary, the trigger level may be readjusted. For this type of operation, the relationship of one division to 45° no longer holds. Instead, the following equation must be used:

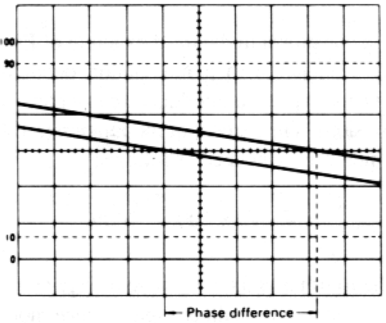
$$\text{Phase Difference} = \text{Hor Div} \times 45^\circ/\text{Div} \times \frac{A}{B}$$

where:
A = New step main time base control setting.
B = Original step main time base control setting.

A simpler method of obtaining more accuracy quickly is to simply use X10 magnification for a scale factor of 4.5°/division.



One cycle adjusted to occupy 8 div.



Expanded sweep waveform display.

Fig. 36. Measuring small phase difference.

Relative Measurements

If the amplitude and period of some reference signal are known, an unknown signal may be measured for amplitude and period without the variable input attenuator and variable time base controls set to the calibrated position. The measurement is made in units relative to the reference signal.

Relative Voltage Measurements
(Refer to Fig. 37)

1. Apply the reference signal to the input jack and adjust the oscilloscope for a normal waveform display. Adjust the Volts/Div and variable input attenuator controls so that the amplitude of the reference signal occupies a fixed number of divisions. After adjusting, be sure not to disturb the variable input attenuator control setting.

2. Calculate the vertical calibration coefficient as follows:

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$$\text{Vertical Coefficient} = \frac{C}{D \times E}$$

where:

C = Amplitude of reference signal (in volts).
D = Amplitude of reference signal (in divisions).
E = step input attenuator setting.

3. Remove the reference signal and apply the unknown signal to the input jack, using only the Volts/Div control to adjust the amplitude for easy observation (do not disturb the variable input attenuator setting).

4. Measure the amplitude of the displayed waveform, in divisions. Multiply the number of divisions by the Volts/Div control setting and the vertical coefficient from above to find the value of the unknown voltage.

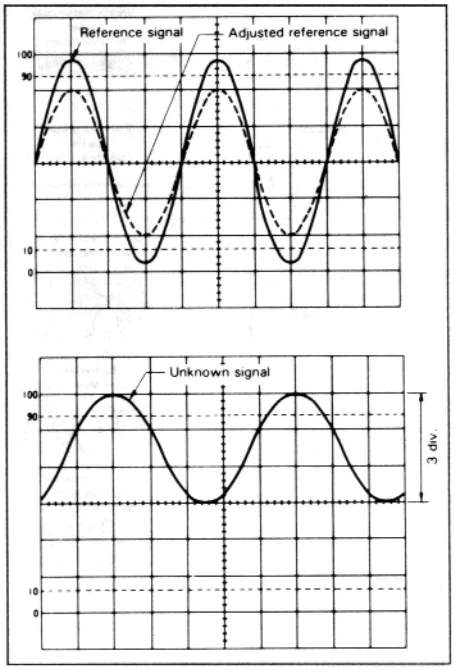

Fig. 37. Voltage measurement, relative, method

The measurement is summarized by the following equation:

Unknown Voltage =
Vert Div x Volts/Div x Vert Coefficient.

For the example shown in Fig. 37, the variable input attenuator control is adjusted so the amplitude of the reference signal is 4 divisions. If the reference signal is 2.0 V p-p, and the Volts/Div control setting is 1 V, the vertical coefficient is 0.5, which was calculated as follows:

$$\text{Vertical Coefficient} = \frac{2\ (\text{V})}{4\ (\text{div}) \times 1\ (\text{V/div})} = 0.5$$

For the example shown in Fig. 37, the amplitude of the unknown signal is 3 divisions, and the previously calculated vertical coefficient is 0.5. If the Volts/Div control setting is 5 V, the unknown signal is 7.5 V p-p. which was calculated as follows:

Unknown Voltage =
3 (div) x 5 (V/div) x 0.5 (vert coef)
=7.5 V

Note:
It is preferable that the reference voltage be the peak-to-peak value, as in the previous example. The measurement holds true for all waveforms if a p-p reference is used. It is also possible to use an rms value for the reference voltage. The unknown voltage value will also be in rms, but the measurement holds true only if both the reference and unknown signals are undistorted sine waves.

Relative Period Measurements
(Refer to Fig. 38)

1. Apply the reference signal to the input jack and adjust the display for a normal waveform display. Using the Time/Div and variable time base controls, adjust one cycle of the reference signal to occupy a fixed number of horizontal divisions. After this is done, be sure not to disturb the variable time base control setting.

2. Calculate the sweep (horizontal) calibration coefficient using the following equation:

$$\text{Sweep Coefficient} = \frac{F}{G \times H}$$

where:

F = Period of reference signal (seconds).

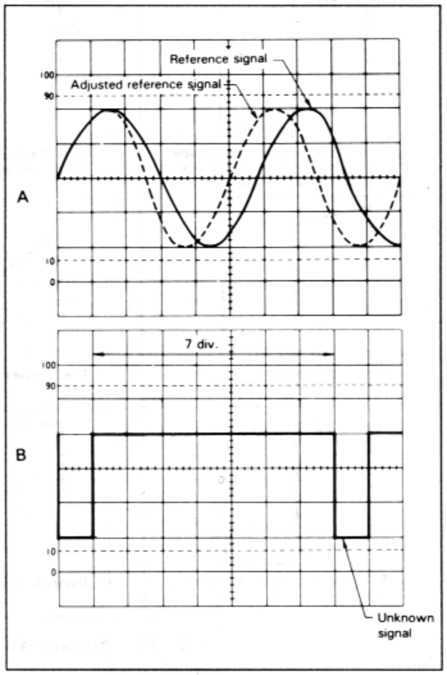

Fig. 38. Period measurement, relative, method

G = Horizontal width of reference signal (divisions).
H = Step main time base control setting.

3. Remove the reference signal and apply the unknown signal to the input jack, using only the Time/Div control to adjust the width of the display (do not disturb the variable time base control setting).

4. Measure the width of one cycle of the displayed waveform, in divisions. Multiply the number of divisions by the Time/Div control setting and the sweep coefficient from above to find the period of the unknown waveform.

The measurement is summarized by the following equation:

Unknown Period =
Horizontal Divisions x Time/Div
x Sweep Coefficient.

For the example in Fig. 38a, the variable time base control is adjusted so the reference signal occupies 5 horizontal divisions. If the reference signal is 1.75 kHz and the Time/Div control setting is 0.1 mS, the sweep coefficient is calculated as follows:

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Sweep Coifficent =

$$\frac{1.75 \text{ kHz-1}}{5 \text{ (div)} \times 0.1 \text{ (ms/div)}} = 1.143$$

For the example in Fig. 38b, the width of the unknown signal is 7 divisions, and the previously calculated sweep coefficient is 1.143. If the Time/Div control setting is 0.2 mS, the period is calculated as follows:

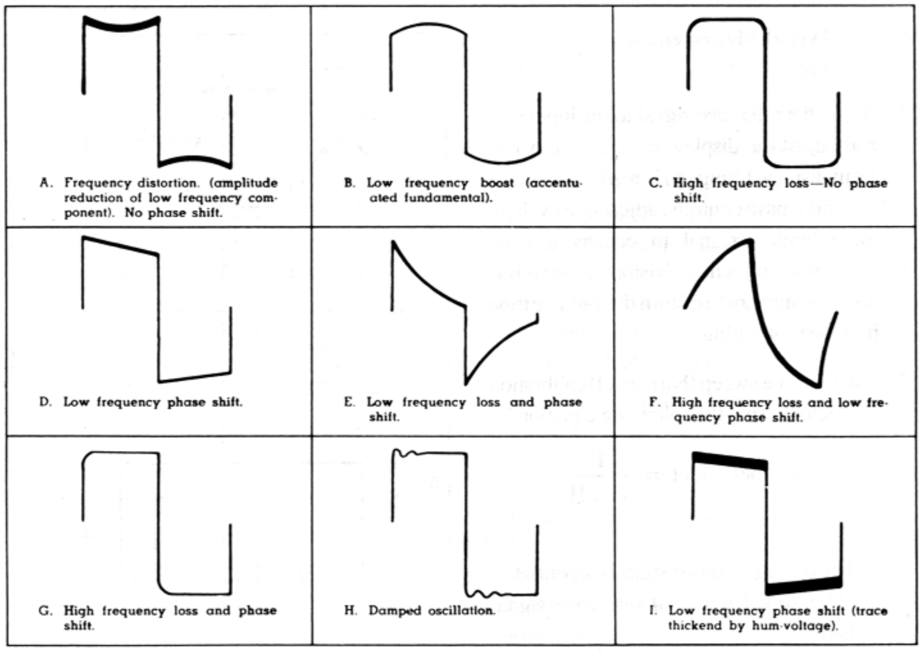
Unknown Period =
7 (div) x 0.2 (mS/div) x
1.143 (sweep coef)
= 1.6 ms.

Using Square Waves To Test Amplifiers

(Refer to Fig. 39)

A square wave generator and an oscilloscope can be used to display various types of distortion present in electronic circuits. A square wave of a given frequency contains a large number of odd harmonics of that frequency. If a 500 Hz square wave is injected into a circuit, frequency components of 1.5 kHz, 2.5 kHz, and 3.5 kHz are also produced. Since most amplifiers do not have uniform gain throughout a wideband width, it is difficult to amplify and reproduce a square wave faithfully. Junction capacitances, stray capacitances, and limited device response are a few of the factors which prevent faithful reproduction of a square wave signal. A well designed amplifier can minimize the nonlinearities caused by these limitations, but a poorly designed or defective amplifier can introduce these nonlinearities to the point where its performance is unsatisfactory.

By injecting a 500 Hz sine wave into an amplifier, response is evaluated only at 500 Hz. However, since a square wave contains a large number of harmonics, by injecting a 500 Hz square wave into an amplifier, we can determine amplifier response for inputs from 500 Hz up to the 21st harmonic.



A. Frequency distortion. (amplitude reduction of low frequency component). No phase shift.

B. Low frequency boost (accentuated fundamental).

C. High frequency loss—No phase shift.

D. Low frequency phase shift.

E. Low frequency loss and phase shift.

F. High frequency loss and low frequency phase shift.

G. High frequency loss and phase shift.

H. Damped oscillation.

I. Low frequency phase shift (trace thickend by hum-voltage).

Fig. 39. Square wave analysis waveform.

The need for square wave evaluation becomes apparent if we realize that during normal use, some audio amplifiers will be required to pass a large number of different frequencies simultaneously. With a square wave, we have a controlled signal with which we can evaluate the input and output quality of a signal of many frequencies (the harmonics of the square wave), much like the amplifier sees when amplifying complex waveforms of musical instruments or voices.

The square wave output of the signal generator must be close to ideal (no tilting or aberrations) so that it does not contribute to any aberration that may be observed when evaluating amplifier response. The oscilloscope vertical input coupling should be set to DC as it will introduce the least distortion, especially at low frequencies. When checking amplifier response, the frequency of the square wave input should be varied from the low end of the amplifier bandpass up toward the upper end of the bandpass. However, because of the harmonic content of the square wave, distortion of the waveform will occur before the upper end amplifier bandpass is reached.

It should be noted that the actual response check of an amplifier should be made using a sine wave signal. This is especially important in limited bandwidth amplifiers. The square wave signal provides a quick check of amplifier performance and will give an estimate of overall amplifier quality. The square wave also will reveal some deficiencies not readily apparent when using a sine wave signal. Whether a sine wave or square wave is used for testing the amplifier, it is important that the manufacturer's specifications be known in order to properly judge its performance.

1. Connect the output of a square wave generator to the input of the amplifier to be tested.

2. Connect a probe to the oscilloscope's channel 1 input. Connect the probe tip to the output of the amplifier being tested (use a resistive load).

3. If the DC component of the circuit being tested is sufficiently low to allow both the AC and DC components of the signal to be viewed simultaneously, use DC input coupling. The AC position may be used without affecting results, except at very low frequencies (below 5 Hz).

4. Adjust the oscilloscope controls for a stable display of one complete cycle of the square wave at a convenient height.

5. For a close-up view of a portion of the square wave, use the X10 magnification and horizontal position control to bring the desired portion to the center of the CRT.

Refer to Fig. 39 for an analysis of waveforms likely to appear during square wave testing of amplifiers. Distortion can be classified into three distinct categories:

- The first is frequency distortion and refers to the change from normal amplitude of a complex waveform. In other words, the introduction in an amplifier circuit of resonant networks or selective filters created by a combination of reactive components will create peaks or dips in an otherwise flat frequency response curve.
- The second is non-linear distortion and refers to a change in waveshape produced by the application of the waveshape to non-linear components or elements.
- The third is delay or phase distortion, which is distortion produced by a shift in phase between one or more components of a complex waveform.

In actual practice, a reduction in amplitude of a square wave component (sinusoidal harmonic) is usually caused by a frequency-selective network which includes capacitance, inductance, or both. The presence of C or L introduces a difference in phase angle between components, creating phase distortion or delay distortion. Therefore, in square wave testing of practical circuitry, we will usually find that the distorted wave includes a combination of amplitude and phase distortion clues. The different waveforms in Fig. 39 sum up the clues as follows:

A. If the combination of elements in the amplifier circuitry were such as to only depress the low frequency components of the square wave, a display similar to Fig. 39A would be obtained.
B. If the opposite condition were the case and the amplifier circuitry boosted only low frequency components of the square wave, a display similar to Fig. 39B would be obtained.

C. The short rise time which occurs at the beginning of the half-cycle is created by the in-phase sum of all the medium and high frequency sine wave components. The same holds true for the rapid droop at the end of the half cycle from maximum amplitude to zero amplitude. Therefore, a reduction in amplitude alone of the high frequency components should produce a rounding at all four points of one square wave cycle as shown in Fig. 39C.

D. If the combination of elements in the amplifier circuitry were such as to only shift the phase of the low frequency components of the square wave, a display similar to Fig. 39D would be obtained.

E. Since a reduction in amplitude of the low frequency components is usually caused by reactive components, a shift in the phase of the low frequency components would be likely to occur in addition to the attenuation of low frequency components. This would cause a display similar to Fig. 39E.

F. If the combination of elements in the amplifier circuitry were such as to decrease the high frequency components of the square wave and cause phase shift to the low frequency components, a display similar to Fig. 39F would be obtained.

G. If the combination of elements in the amplifier circuitry were such as to attenuate and shift the phase of the high frequency components of the square wave, a display similar to Fig. 39G would be obtained.

H. If the amplifier circuitry boosted the high frequency components of the square wave but the network in the amplifier were damped, a display similar to Fig. 39H would be obtained. Lighter damping would cause more oscillation (the sinusoidal shape at the beginning of the leveling off period) and heavy damping would decrease oscillation.

I. If the combination of elements in the amplifier circuitry were such as to shift only the phase of the low frequency components of the square wave, but power supply filtering were also poor (thus introducing line voltage hum) a display similar Fig. 39I would be obtained.

X-Y Mode Applications

Phase Measurements

(Refer to Fig. 40)

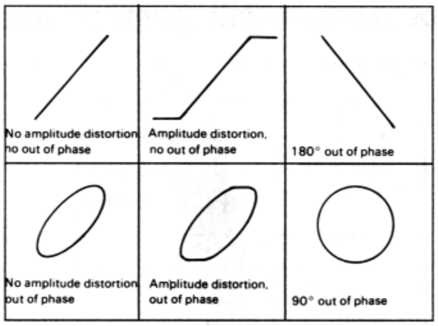

No amplitude distortion no out of phase
Amplitude distortion, no out of phase
180° out of phase
No amplitude distortion out of phase
Amplitude distortion, out of phase
90° out of phase

Fig. 40. Typical X-Y phase measurement displays

A dual-trace method of phase measurement was previously described. A second method of phase measurement requires calculations based on the Lissajous patterns obtained using X-Y operation. Distortion due to non-linear amplification can also be displayed.

A sine wave is applied to the audio circuit being tested. The same sine wave is also applied to the vertical input of the oscilloscope, and the output of the tested circuit is applied to the horizontal input of the oscilloscope. The amount of phase difference between the two signals can be calculated from the resulting waveform.

1. Using an audio generator with a pure sinusoidal signal, apply a sine wave test signal at the desired test frequency to the audio network being tested.

2. Set the signal generator output for the normal operating level of the circuit being tested. If desired, the circuit's output may first be observed on the oscilloscope with normal sweep operation. If the test circuit is over driven, the sine wave display on the oscilloscope is clipped and the signal level must be reduced.

3. Connect channel 1 to the input and channel 2 to the output of the test circuit. Set channel 1 and 2 Volts/Div and variable input attenuator controls for exactly the same amplitude waveforms on the display in normal sweep operation.

4. Select X-Y operation.

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5. If necessary, repeat step 3, readjusting the channel 1 and 2 gain controls for a suitable viewing size. Some typical results are shown in Fig. 40.

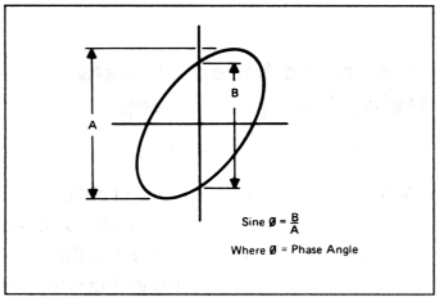

Fig. 41. Phase measurement, X-Y operation.

If the two signals are in phase, the oscilloscope trace is a straight diagonal line. If the vertical and horizontal gain are properly adjusted, this line is at a 45° angle. A 90° phase shift produces a circular oscilloscope pattern. Phase shift of less (or more) than 90° produces an elliptical oscilloscope pattern. The amount of phase shift can be calculated from the oscilloscope trace as shown in Fig. 41.

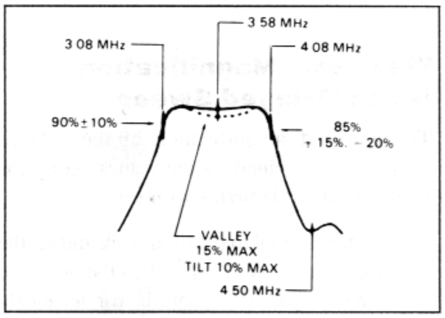

Fig. 42. Frequency response measurement.

Frequency Response Measurements
(Refer to Figs. 42 and 43)

A sweep generator and the X-Y mode of the oscilloscope maybe used to measure the audio or rf frequency response of an active or passive device, such as an amplifier, band pass filter, coupling network, etc.

1. Refer to Fig. 42. Connect the audio or rf output of the sweep generator to the input of the circuit under test and the output of the test circuit to Y axis input (vertical axis) of the oscilloscope. A demodulator probe will give a "text book" frequency response display as shown in Fig. 43, but a standard probe can be used which will result in an envelope display.

2. Connect the sweep ramp voltage of the sweep generator to the X axis input of the oscilloscope.

3. Set the oscilloscope for X-Y operation and adjust the channel 1 and 2 controls for a suitable viewing size.

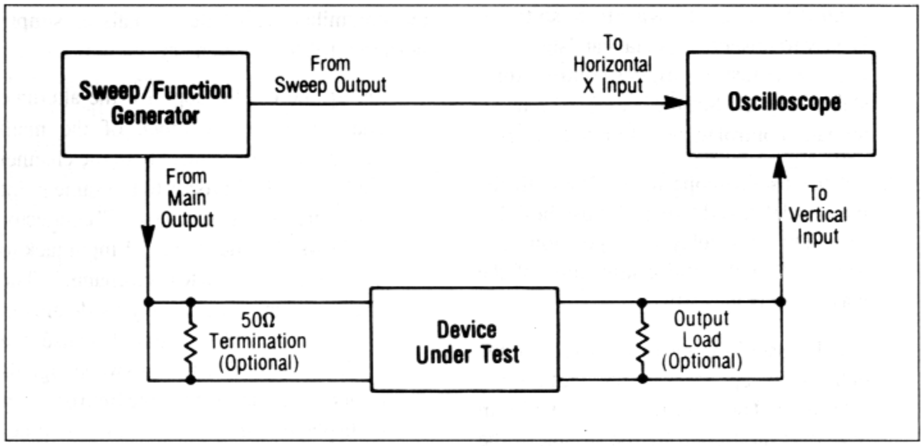

Fig. 43. Frequency response test set-up.